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PISA and biology school textbooks: the role of visual material

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Abstract

Language is essential in doing science and shapes the construction and communication of scientific ideas. The language of science is an integration of texts, visual images (i.e. diagrams, pictures, graphs, maps, tables, charts) and mathematical expressions (i.e. equations). Learning and teaching science means also learning and teaching the media of science communication. This study aims at comparing visual material included in PISA science test items related to biological systems and in assessment tasks in Biology school textbooks intended for 7th and 9th grade students in Greece.
Specifically, the following dimensions of the visual material were analyzed:

- The frequency of its inclusion in PISA and textbook items;
- Its type (e.g. photographs, diagrams, tables);
- Its role within items, ranging from visual images functioning as concrete representations of verbal descriptions displaying redundant information to the relevant questions, to graphics providing partial information that is necessary, but not sufficient, for answering the questions, and to images containing all information that the test taker needs for answering the questions;
- The format of the required answers (i.e. completion of graphs, or tables, visual cues, free graphical response, verbal or numerical response).

The results reveal tensions between visual images comprised in PISA and textbook assessment items according to the aforementioned dimensions. This indicates that Greek students' limited familiarity with the types and function of visual material used by PISA could be a possible factor –among others– for interpreting their low achievement in the PISA survey.

Keywords: Assessment tasks, Biology, PISA, school textbooks, visual material;

1. Introduction

This paper aims at exploring the role of visual material embedded in PISA science test items related to biological systems and in Biology school textbooks assessment tasks intended for 7th and 9th grade students in Greece. Several studies have suggested that students' diagrammatic literacy, i.e. the ability to interpret and produce graphical representations is important for success in standardised science tests (e.g. Mayer, 1997; Schnotz, Picard & Hron, 1993; Yeh & Mc Tigue, 2009). Moreover, differentiations between PISA test items, school textbooks and school based examination test items regarding the role of the visual material included are considered as one –among others-

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factor explaining the low performance of Greek students in PISA. (Anagnostopoulou, Hatzinikita, Christidou & Dimopoulos, 2011; Anagnostopoulou, Hatzinikita & Christidou, in press; Hatzinikita, Dimopoulos & Christidou, 2008).

Language is essential in doing, teaching and learning science, as it shapes the construction and communication of scientific ideas. The natural language of science is an integration of texts, visual images (i.e. diagrams, pictures, graphs, maps, tables, charts) and mathematical expressions (i.e. equations). Text, mathematics and visual images are needed to represent scientific concepts and explanations, because these are abstract and complex, hence visual representations facilitate the presentation of abstract concepts with concrete depictions. Furthermore, visual representations are the best medium to describe topics such as continuous variation, shape and movement in space as well as matters of proportion and ratio (e.g. Lemke, 1998; Prain, Tytler & Peterson, 2009; Yeh & Mc Tigue, 2009).

The key to understand and learn a subject is to understand its language, therefore understanding the different modes that formulate science language is crucial for learning science. Learning from a combination of verbal and visual representations not only results in better retention of the information than learning from text alone, but also results in better understanding of the subject matter than simple verbal representation, since students understand natural phenomena better when studying text combined with pictures than when studying text alone (e.g. Levie & Leutz, 1982; Levin et al., 1987; Mayer, 1997). Multiple representations support deeper understanding because they can complement each other by providing complementary information (Ainsworth 1999, 2006).

According to cognitive theories derived from theories of dual coding, cognitive load and generative learning, meaningful learning involves both verbal and visual input, as well as opportunities to integrate these inputs through five distinct cognitive processes: word selection, image selection, word organization, image organization and the integration of words and images using also prior knowledge (Meyer, 2005). An integrative model of verbal and visual comprehension is developed based on the abovementioned cognitive theories as well as on recent approaches on text and graphic comprehension assuming that in understanding an external representation the human mind constructs multiple internal (mental) representations (Schnotz & Kürscner 2008). This model puts emphasis on the interactions between words and images as well as between verbal and visual mental representations and enlightens the contribution of visual representations to teaching, learning and assessing scientific topics.

In addition, recent approaches on science education focus on the concept of scientific literacy, i.e. students' ability to use knowledge acquired in school in everyday life situations. Scientific literacy requires that students are proficient in science language, i.e. at interpreting and creating multimodal representations, since graphs and diagrams can bridge the gap between everyday knowledge based on verbal description and scientific formalism conveyed by mathematical formulas describing the central laws of the content area. Scientific representations based on graphs and diagrams reflect deeper understanding and are better suited to make predictions or draw conclusions. Diagrams and graphs are broadly applicable and can therefore be used as tools for knowledge transfer (e.g. Osborne, 2002; Stern, Aprea & Ebner, 2003; Yore & Treagust, 2006).

Literacy is also the core element of the PISA survey, one of the largest-scale international comparative surveys aiming to perform a cross-national assessment of reading, mathematical and scientific literacy of 15-year-old students and to inform educational policies of participating countries.

These attempts, combined with an increasing media and political interest which follows publication of PISA results, have encouraged many researchers to focus on this survey and carry out relevant empirical research.

At present, most of these studies use PISA-generated datasets in order to explore factors (related to students, schools and educational systems) that could influence students' achievement, while only a few studies have focused on PISA test items and a very limited number of studies attempt to consider the PISA framework and test items with reference to national contexts and especially to national curricula (Anagnostopoulou et al., 2011).

PISA assesses students' ability to transfer the knowledge and skills acquired in school in novel settings in order to participate fully in society as reflective citizens. The core element of the PISA survey regarding science is the concept of scientific literacy (OECD, 2006). It refers to an individuals':

"- Scientific knowledge and use of that knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science-related issues

- Understanding of the characteristic features of science as a form of human knowledge and enquiry

- Awareness of how science and technology shape our material, intellectual, and cultural environments
- Willingness to engage in science-related issues and with the ideas of science, as a reflective citizen" (OECD, 2006 p.23).

For assessing scientific literacy PISA uses test units comprising stimulus material consisting of text, images, tables, graphs followed by questions (test items) related with the stimulus material. This unit structure is considered as facilitating the simulation of a context that is as realistic as possible and reflects the complexity of everyday situations (OECD, 2006).

On the one hand, PISA explicitly moves beyond school curricula to a broader conceptualization of literacy that requires the transfer of knowledge in novel settings. On the other hand, visual representations are considered as a powerful transfer tool necessary for success in science test items as mentioned above. Therefore, it is of interest to explore possible convergences and divergences between visual material included in PISA test items and in assessment tasks embedded in school textbooks. The Greek educational system is particularly centralised, and thus a unique school textbook prepared by official state bodies for all school types –public and private ones– is prescribed for mandatory use. In such a context the format and the content of the assessment tasks embedded in science school textbooks are considered to have a significant impact on teaching and learning. In a previous study (Anagnostopoulou et al., in press) focusing on the role of visual images embedded in PISA and school-based examination test items it is indicated that there are significant discrepancies between the abovementioned sets of visual material regarding their type, functional role and format of required answer. By applying the same theoretical and methodological framework for comparing PISA test items related to biology and assessment tasks embedded in Biology school textbooks, the present study should complement the comparison between test items used in the contexts of school science teaching in Greece and the PISA survey and potentially provide valuable insight on Greek students' low achievement in PISA. Moreover, possible discrepancies between the abovementioned sets of test items could put forward implications for science textbooks and curriculum design, science educators' teaching practices, as well as students' assessment in the direction of scientific literacy.

2. Method

2.1. Sample

The sample of this study consists of: (a) publicly available PISA test items related to the content area of living systems and the context 'life, health, and environment', and (b) the assessment tasks embedded in biology school textbooks, intended for 7th and 9th grade Greek students accordingly†.

Although PISA test items are considered as confidential since they could be reused in future assessment cycles, some examples of test items have become publicly available by PISA authorities. From those examples 24 test units (consisting of 65 test items) were identified in PISA publications as related to living systems and the context 'life, health, and environment' and were included in the sample of the present study. Since these publicly released items are intended to be read as exemplars, it could reasonably be argued that they are representative and consequently that they reflect the rationale promoted by PISA.

In regards to assessment tasks in biology school textbooks, 315 assessment tasks were analysed. All visual images included in the PISA test unit stimulus texts and/or test items related to living systems and in biology school textbooks assessment tasks were analysed. Each visual image was considered as a single unit of analysis. Following this procedure, two samples of 26 and 129 visual images were collected from the PISA test units and the assessment tasks in biology school textbooks respectively.

† In Greece biology is taught at the 7th and 9th grades.

2.2. The framework of analysis for the visual representations

When students face a visual representation they have to undertake complex cognitive tasks: understand the type of the representation (i.e. how it encodes information), understand the relation between the representation and the subject matter and understand how to select and retrieve the appropriate information (i.e. the functional role of a visual representation). (Ainsworth, 2006)

Taking into account all the above mentioned visual representation characteristics that are considered to be related to the difficulties students face as they deal with a visual image, a three-tired framework was constructed in order to analyze the PISA test items as well as the assessment tasks included in biology school textbooks regarding the type, the functional role of graphs and the format of the required test. These axes of analysis, along with their distinct categories, are described below.

- *The type of visual representations*. The classification of the visual images was based on Moline's categorization system (1995), modified to meet the needs of this study. The following types of visual representations were identified: photographs, naturalistic drawings, stylized drawings, picture glossaries, flowcharts, cutaway exhibitions, graphs (diagrams, histograms) and tables.

- *The functional role of graphs*. The following three-levelled scale proposed by Yeh and Mc Tigue (2009) was adopted in order to analyze the test items regarding their functional role.

- Level 1: At the lowest level, a visual representation displays redundant information to the questions themselves. Such graphics are deemed unnecessary for answering the question because, without the graphical support, the question could still be answered correctly.
- Level 2: At this level, a visual representation provides partial information that is necessary, but not sufficient, for answering the question. That is, students need to derive information from the visual representations, the verbal question, and their prior knowledge in order to complete the task.
- Level 3: At level three, a visual representation contains all necessary information for answering the question. The students have to interpret and typically reorganize the information in order to answer the question. However, they don't rely on their prior knowledge, but instead they need procedural knowledge to produce an adequate answer.

- *The format of the required test answers*. The test items were analyzed regarding the kind of answer they require. Three kinds of formats were identified:

- Built-in answers including multiple choice answers, graph completion (e.g. mark the appropriate cell of a table with a sign) and visual cues (e.g. select the correct visual object).
- Open ended responses including free verbal responses, free graphical responses (e.g. construct a diagram displaying a given relationship) and chart completion with free verbal response (e.g. fill in a table).
- Hybrid answer formats, i.e. a combination of built-in and open ended responses.

3. Results

In this section the results of analysis of the visual images are presented regarding the frequency of their inclusion in evaluation test items, their type, their functional role within test items and the format of the required test answers. The results are also presented in Table 1.

The frequency of visual images' inclusion: Both PISA test units and assessment tasks included in biology school textbooks use the visual mode quite frequently, since an average of 0.4 images corresponds to each test item.

The type of the visual representation: As illustrated in Table 1, PISA test items related to the content area of living systems include in their majority graphs (30.8%), naturalistic drawings (26.9%) as well as photographs (23.1%), while images introduced in assessment tasks in biology school textbooks are mostly cutaway exhibitions (27.9%) and tables (26.4%,). It is worth noting that only one graph is included in the assessment tasks in biology school textbooks.

The functional role of graphs: Results in Table 1 also indicate that PISA test items' visual material tends to follow a balanced distribution in terms of function. Therefore, 34.6% of visual representations contain all necessary information for answering the question (level 3), and a significant part of the sample (30.8%) seems to provide essential but not sufficient information (level 2) for answering the question. Nevertheless, this is not the case for assessment tasks in biology school textbooks: visual representations either play a marginal role in the comprehension and successful accomplishment of the tasks (level 1: 41.9%) or carry partial information (level 2: 51.2%).

The format of the required test answers: The majority of the analysed PISA test items require built-in answers (53.8%) while the vast majority (77.5%) of the assessment tasks in biology school textbooks requires an open ended response.

Table 1. The results of analysis of the visual images

	PISA			**Assessment tasks in Biology school textbooks**		
	N	**Percentage**	**Images per item**	**N**	**Percentage**	**Images per item**
Frequency of visual images' inclusion						
Number of items including visual representations (total)	26	40%	0.4	129	41,0%	0.4
Number of items including one visual representation	22	33.8%		90	28,6%	
Number of items including two visual representations	2	3.1%		6	1,9%	
Number of items including three visual representations	0	0.0%		3	1,0%	
Number of items including four visual representations	0	0.0%		2	0,6%	
Number of items including five visual representations	0	0.0%		2	0,6%	
Type of visual images						
Photograph (The photograph of a subject or scenery)	6	23.1%		15	11,6%	
Naturalistic drawing (All the features of the subject are depicted in detail)	7	26.9%		13	10,1%	
Picture glossary (Parts of the pictures are named with labels)	0	0.0%		3	2,3%	
Flow chart (Arrows or numbers are marked among stages)	1	3.8%		6	4,7%	
Table (Tables are composed of cells)	3	11.5%		34	26,4%	
Graph (diagram/histogram) (Quantity information is recomposed in the format of relative graphs)	8	30.8%		1	0,8%	
Cutaway exhibition (Internal parts or processes are marked with labels)	0	0.0%		36	27,9%	
Stylized drawing (Graphics are delineated only with the outlines or in a symbolic drawing)	1	3.8%		19	14.7%	
Hybrids (Two or more graphics mentioned above are involved).	0	0.0%		2	1,6%	
Functional role of visual images						
Level 1	9	34.6%		54	41,9%	
Level 2	8	30.8%		66	51,2%	
Level 3	9	34.6%		9	7,0%	
Format of required answers						
Built-in answers	14	53.8%		23	17,8%	
Open ended responses	11	42.3%		100	77,5%	
Hybrids	1	3.8%		6	4,7%	

4. Conclusions

The abovementioned results indicate notable discrepancies between PISA science test items and biology school textbook assessment tasks regarding the visual images they include. Visual images included in PISA test items are in their majority graphs, naturalistic drawings as well as photographs. On the other hand, most of the visual images included in biology school textbooks' assessment tasks are tables and cutaway exhibitions. Graphs and tables are considered as powerful tools for communicating scientific concepts and explanations. However, if the functional role of visual representations is taken into account, the image changes significantly. Only a few visual representations included in biology school textbooks' assessment tasks contain all the necessary information for answering the question (level 3), indicating that tables included in biology school textbooks' assessment tasks provide either redundant (level 1) or not sufficient information for answering the question (level 2). Consequently, science textbooks tend not to use visual images in order to communicate scientific information.

Additionally, a significant part of PISA visual images corresponds to photographs and naturalistic drawings introducing everyday life contexts. At the same time PISA test items' visual material tends to follow a balanced distribution in the three function levels, indicating that graphs included in PISA test items appear to communicate scientific information in everyday life contexts, bridging the gap between everyday life and scientific knowledge.

These findings are in accordance with the findings of a previous study (Anagnostopoulou et al., in press) where the differentiations revealed between the same sample of PISA test items and school-based biology examinations test items regarding the use of the visual images were even more intense. More specifically, school-based examination test items rarely include visual images, while the majority of the visual representations they involve are deemed unnecessary for answering the question (level 1). Therefore, PISA items convey significant scientific messages primarily through their visual parts, whereas in school-based examinations biology items the visual part seems to have a purely decorative role.

Considering that students' achievement is related to their familiarization with the context of a test item (Cooper & Dunne, 2000; Morais & Abtunes, 1994; Morais & Miranda, 1996) it could be argued that if students are already familiarised with particular types and functions of visual representations, then they could understand and successfully cope with the required tasks, if these tasks incorporate images with familiar types and functions (Ainsworth, 2006). Therefore –and also taking into consideration the crucial role of evaluation in school practice in Greece (Zisimopoulos, Kafetzopoulos, Moutzouri-Manousou & Papastamatiou, 2004)–, the lack of attention to the visual component in school-based examination tests and the abovementioned notable divergences between PISA test items and assessment tasks in school textbooks could restrict Greek students' ability to produce appropriate responses in PISA assessment: they are not acquainted with relying on visual representations in order to gain information for answering test items. This factor could be related to Greek students' low achievement in PISA.

The findings of this study along with the outcomes of other studies (Anagnostopoulou et al., 2011; Anagnostopoulou et al., in press) could be used as a basis for possible implications. It appears to be crucial for school science teaching and learning to familiarise students with various types of visual representations and teach them to rely on them in order to gain substantial information. In this direction the official and mandatory science textbooks could be complemented by other material (e.g. newspaper articles, etc) that would rely more on the visual mode than actual textbooks. Also, evaluation items using the visual mode more intensively could be developed and used. These implications would enhance students' visual and hence scientific literacy.

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